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HUMAN RESOURCES

EFFECTS OF FIELD-OF-VIEW SIZES ON POP-UP WEAPONS DELIVERY

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It is commonly believed that flight simulators capable of supporting tactical combat tasks should possess full-field-of-view visual displays with high levels of brightness and resolution. The problem of designing such a visual system is that the three factors (field-of-view, brightness, resolution) are not independent. For instance, as field-of-view (FOV) is increased, brightness and resolution decrease. An attempt to overcome this dilemma uses head-driven visual displays with instantaneous limited-FOV sizes. Head-driven systems overcome the full-FOV problem by providing a full field of regard for the head-driven instantaneous FOV. Important considerations for head-driven instantaneous systems are the horizontal (H) and vertical (V) dimensions of the instantaneous FOV. The present research examines the effect of the instantaneous FOV size on pilots' ability to perform pop-up weapons deliveries using both stationary and head-driven visual displays. The FOV sizes investigated were 127^{o}H x 36^{o}V, 160^{o}H x 60^{o}V, 160^{o}H x 88^{o}V, and 180^{o}H x 88^{o}V. A 300^{o}H x 150^{o}V size provided a full-FOV control condition. An A-10 dodecahedron simulator configured with a 7-window color light valve display, computer-generated imagery, and a Polhemus magnetic head-tracker provided the cockpit and display apparatus. Aircraft performance measures (altitude, airspeed, etc.), head position

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data, and bomb miss distance were the dependent measures. Ten F-5 instructor pilots served as subjects for the experiment and flew all combinations of FOV sizes and display types from five initial points. The results did not confirm the initial hypothesis that performance would be better for head-driven conditions and larger fields-of-view. This may be due to an increased use of instruments in the smaller FOV conditions to maintain performance levels. This conclusion is difficult to verify, because no eye position data are available. However, it is clear that the smallest condition ($127^{o}H \times 36^{o}V$) is inadequate to support training of this task.

PREFACE

This research and development (R&D) effort was conducted by the Operations Training Division of the Air Force Human Resources Laboratory (AFHRL), Air Force Systems Command (AFSC), and was supported by the 425th Tactical Fighter Training Squadron (TFTS) at Williams Air Force Base, Arizona. The work was performed in support of the Training Technology objectives of the present AFHRL Research and Technology Plan. This R&D falls under the specific goal of Visual Scene and Display Requirements by identifying and demonstrating cost-effective ways of developing and maintaining new skills to enhance job performance and combat readiness.

The authors would like to express sincere appreciation to the members of the 425th TFTS for their cooperation throughout this effort, and in particular to Major Ron Grattop, Capt Scott Petry, and Lt Col Jim Anderson. The authors would also like to thank Mr. Vincent Ditore for his contributions throughout the effort and Dr. David Hubbard for his assistance in analyzing the data.

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EFFECTS OF FIELD-OF-VIEW SIZES ON POP-UP WEAPONS DELIVERY

I. INTRODUCTION

The design of current flight simulator visual systems must take into account the interaction between field-of-view (FOV) size, brightness, and resolution in order to ensure training and cost effectiveness. The final design of a visual system depends on the type of task to be trained, experience level of the trainees, and level of image detail needed. For example, a simulator designed to train low-level flight may need a full-field-of-view visual display and high levels of brightness and resolution so that pilots can determine altitude or locate objects on the surface.

Three design approaches that have been investigated are (a) head-slaved display systems with instantaneous FOV sizes, (b) full-FOV domes or window-based displays, and (c) limited-FOV domes or window-based displays. One of the main questions to be addressed is what horizontal and vertical dimensions are needed for the instantaneous FOV size. This question can be addressed by systematically changing the instantaneous FOV size for a number of tasks and determining its effect on pilot performance and/or head movement. Air-to-ground tasks have received the greatest attention with respect to experimental research to determine instantaneous FOV size.

The first research involving the use of an instantaneous FOV was in 1976 (Hutton, Burke, Englehard, Wilson, Rumaglia, & Schneider, 1976). The objective of this research was to determine if a head-slaved instantaneous field-of-view display could help satisfy full-FOV requirements for air-to-ground tasks. The results of this effort revealed that a 60° horizontal instantaneous field-of-view is inadequate for air-to-surface tasks and that further experimentation was needed to determine the effects of such systems on pilot performance.

LeMaster and Longridge (1978) examined the effects of various FOV sizes on conventional gunnery range weapons delivery in simulated tactical deliveries The results indicated that a head-driven instantaneous FOV size as small as 90° horizontal (H) X 70° vertical (V) could be used without seriously degrading performance.

Another research effort conducted by Warner (1981) investigated instantaneous FOV size in conjunction with a visual overlap field (high-resolution inset). The results of that study indicated that an FOV as small as an 80°H X 66°V head-driven instantaneous FOV with a 20° visual overlap area did not adversely affect 30° manual dive bombing performance. Other findings were that the Root Mean Square (RMS) of horizontal head movement decreased as the instantaneous FOV increased. The greater RMS of horizontal head movement for the small instantaneous FOV conditions was conjectured to be associated with pilots' compensating for the lack of peripheral information. These results indicate that head-slaved FOV systems can be effectively used to perform high-angle (30°) weapons delivery with an instantaneous FOV size of 80°H X 66°V.

Low-level flight is another important tactical task which may benefit from head-slaved systems. Hughes and Hubbard (1985) performed an experiment in which subjects were instructed to fly through a marked route as low as they safely could. Two instantaneous FOV conditions and a full-FOV condition (300° H X 150° V) were tested. The results indicated that altitude during turns was significantly lower when the peripheral information was occluded. The authors concluded that a head-slaved system is an effective option for various tasks, but control performance may be affected for those tasks that require a high degree of aircraft maneuvering.

An effort performed by Dixon, Krueger, Rojas, and Hubbard (1989) also examined the effects of head-slaved instantaneous FOV size on low-level flight and 30° manual dive bombing tasks.

The previous research used pilots who were experienced in the tasks. This effort investigated the effects of FOV on skill acquisition in the simulator. The results indicated that as the instantaneous FOV size was increased, pilots needed fewer trials to reach the criterion level of performance.

The present investigation attempts to further define instantaneous FOV size requirements for a previously unexamined task (pop-up weapons delivery). The pop-up weapons delivery task was selected due to its unique flight pattern and requirement for out-of-the-window visual cues. The basic pop-up maneuver is illustrated in Figure 1. It involves a low-level approach to a pull-up point selected on the basis of target position. At the pull-up point, a climb angle is established that will allow the pilot to gain sufficient altitude to acquire the target and set up the bomb run. At the appropriate altitude, the pilot rolls in on the target, apexes, rolls out, establishes the correct dive angle, and flies the aircraft to the release point. After delivering the ordnance, the pilot takes evasive action to avoid ground threats and returns to low-level flight. The purpose of the pop-up is to minimize the amount of time that a pilot is vulnerable to ground threats. One consideration that made the pop-up delivery desirable for the study was the requirement to use the vertical dimension of the field-of-view to locate the target during rolling phases. Correct performance of this maneuver requires both instruments and out-of-the-window visual cues. Much of the task can be performed with reliance on instruments, if necessary.

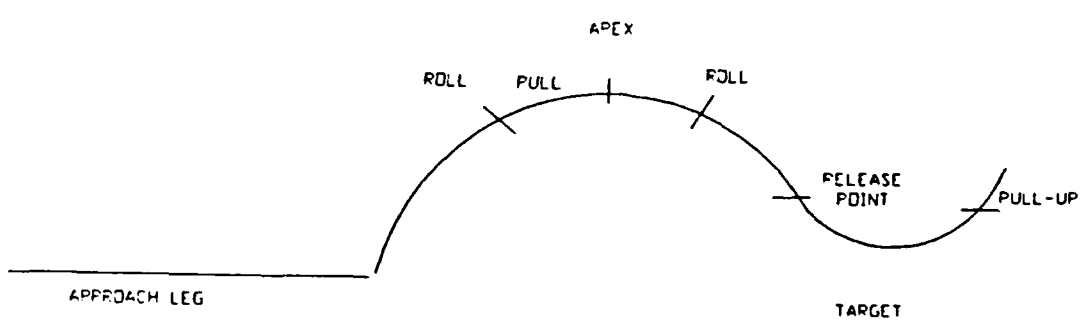

Figure 1. **Pop-up Weapons Delivery Profile.**

The researchers used both head-slaved FOVs and static FOVs to determine the relationship between the various configurations. The selected FOV sizes were based on current stationary FOV dimensions and proposed helmet-mounted FOV dimensions. The selected sizes were 127°H x 36°V, 160°H x 80°V, 160°H x 88°V, 180°H x 88°V, and 300°H x 150°V. The study was designed to provide a clearer understanding of performance differences between static and head-driven FOVs and differences with respect to head movement.

Objective

The objective of the present effort was to determine the pilot performance and head movement tradeoffs for display type (head-tracked systems and stationary display systems) and various FOV sizes. Based on prior studies, it was expected that as FOV size increased: (a) performance would be closer to the ideal flight parameters, (b) head movement would decrease, and (c) head-driven displays would produce superior performance for the smaller FOV sizes.

II. METHOD

Subjects

Ten F-5 instructor pilots from the 425th Tactical Fighter Training Squadron at Williams AFB, Arizona, participated in the study. Their mean total number of flight hours was 1,982, with a range of 1,000 to 4,500 hours.

Apparatus

This research effort was conducted in an A-10 dodecahedron simulator which provides computer-generated imagery for out-of-the-window visual cues. The field of regard for this simulator is 300°H and 150°V. The visual system produces day, dusk, and night scenes through seven channels with seven color light valves on seven 36-inch windows. The Advanced Visual Technology System image generator is capable of producing approximately 8,000 faces and 2,000 point features simultaneously. Additional features include a resolution of 6 arc-minutes, an average brightness of 2 foot-Lamberts, a full color display, and cell texturing.

The imagery can be electronically masked and a Polhemus magnetic head-tracker used to move the masked-out display, thus providing various FOV sizes for research purposes. The head-tracker uses a 3-space system to compute gaze position and angle outputs. The four field-of-view sizes and the simulator field of regard are shown in Figure 2.

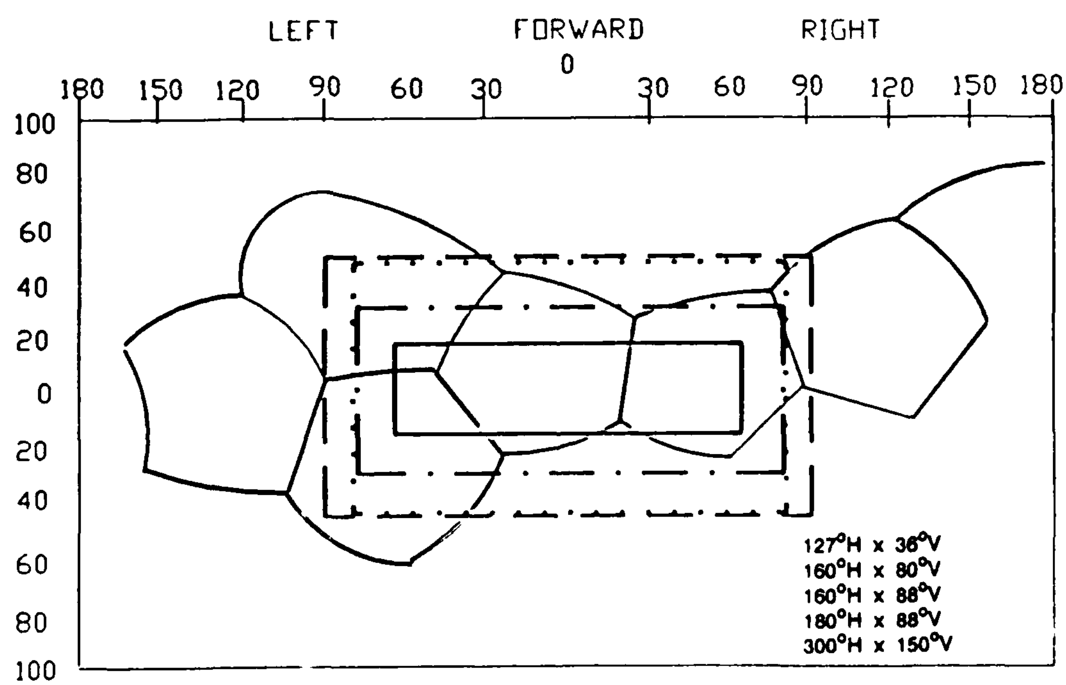

Figure 2. **Instantaneous Field-of-View Sizes.**

Experimental Design

A full-factorial, within-subjects, repeated-measures design was used. The independent variables were field-of-view size, whether the FOV was head-driven or static, and initial headings.

The five instantaneous and stationary FOV sizes were as follows:

1. $127^{o}H \times 36^{o}V$
2. $160^{o}H \times 80^{o}V$
3. $160^{o}H \times 88^{o}V$
4. $180^{o}H \times 88^{o}V$
5. $300^{o}H \times 150^{o}V$

The total viewing volume or field of regard was $300^{o}H \times 150^{o}V$ for the instantaneous FOV sizes and control conditions. The $300^{o}H \times 150^{o}V$ condition was repeated, to give 10 display type conditions.

The means and standard deviations of the variables listed below were used as dependent variables for both discrete and continuous data collection.

Airspeed	Altitude	Pitch	Roll
Yaw	Pitch rate	Roll rate	Yaw rate
Angle of attack	G's	Head pitch	Head roll
Head yaw	Bomb Miss Distance		

Procedure

Each pilot was given a handout describing the parameters and headings for the pop-up trials. The experimenter also went through the handout with the subjects and answered any questions concerning the task.

The pilots were given 5 minutes to familiarize themselves with the A-10 cockpit configuration and the simulator's flight characteristics. Following the orientation, each subject performed five practice pop-up trials, one at each initial condition point, within the $300^{o}H \times 150^{o}V$ FOV.

During the test portion, the subjects performed 50 pop-up trials. The trials were randomly selected from the 10 possible FOV conditions and five initial conditions until all combinations were completed.

Data Analysis

For analysis purposes, the data were analyzed by mission segment. The approach, pull-up to roll 1, roll 1 to apex, apex to roll 2, release point, and bomb impact point comprised the six parts examined. The segments were defined by states of the aircraft parameters. The files were separated into discrete data at the break points. Continuous data were collected at 10 Hertz. The discrete data were used for bomb score analysis and deviations from ideal parameters. The continuous data were used to calculate the Root Mean Squares for head pitch, head roll, and head yaw. The data were analyzed using the SAS GLM software program.

III. RESULTS

Bombing Score Error

There were no significant effects ($\underline{p} \geq .05$) noted for miss distance as a function of FOV size, display type, or the FOV size by display type interaction. The mean bombing error for each FOV size in conjunction with display type (stationary or head-driven) is plotted in Figure 3. The plot displays the associated changes in bomb score as both the horizontal and vertical fields were varied. The best scores were obtained in the 160°H X 60°V stationary FOV and the 180°H X 88°V head-driven instantaneous FOV. Although there were no significant effects, better performance was exhibited in the static conditions in the three smaller FOV sizes.

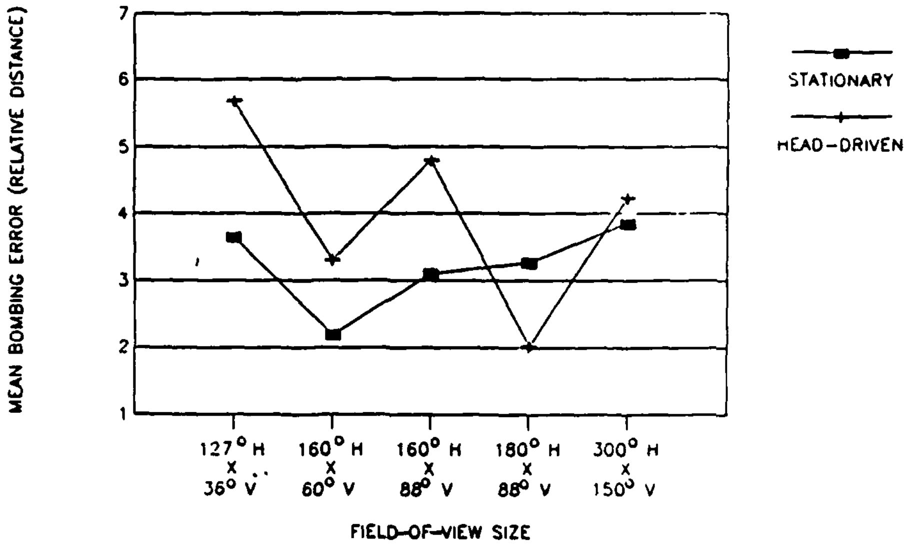

Figure 3. **Bombing Error as a Function of Field-of-View and Display Type.**

RMS Head Movement

Significant effects were found for head roll, head pitch, and head yaw in the various segments for FOV size. The most consistent effects were found for the RMS of head pitch. As shown in Figure 4, the smallest static FOV condition displayed significantly less movement. For conditions greater than 127°H X 36°V, RMS head pitch was essentially identical. Other effects found for RMS head roll and RMS head yaw occurred in the pull-up and roll segments and followed the same trend as RMS head pitch.

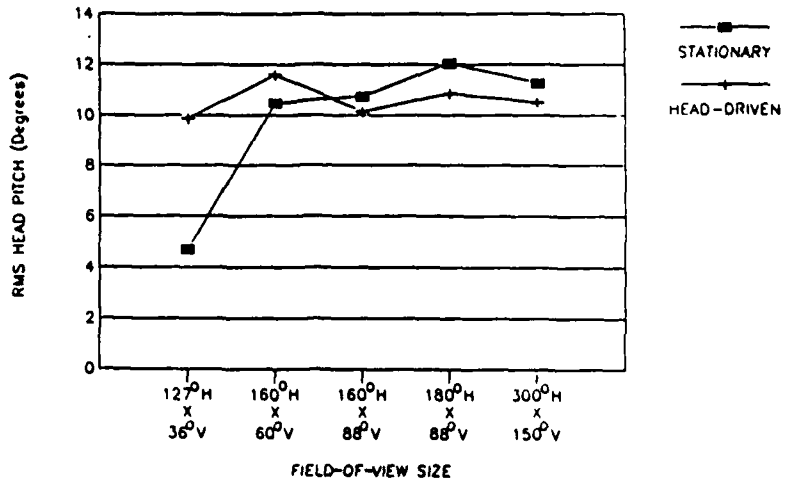

Figure 4. **RMS Head Pitch for Pull-Up Segment.**

Deviations from Ideal Parameters

Data regarding the deviations from ideal parameters were collected at various discrete points along the flightpath. These points were pull-up, roll 1, apex, roll 2, and bomb release. None of the independent variables significantly affected the pull-up point. At the first rolling point, FOV size effects were found for airspeed ($F(4.17) = 6.36$, $p = .0002$), altitude ($F(4,17) = 7.39$, $p = .0001$), and roll rate ($F(4,17) = 7.86$, $p = .0001$). For airspeed, the 160°H X 88°V instantaneous FOV had the smallest deviation. For the altitude and roll rate variables, best performance occurred at the 300°H X 150°V instantaneous FOV size. At the apex point, significant FOV size effects were found for altitude ($F(4,17) = 5.51$, $p = .006$) and yaw rate ($F(4,17) = 3.54$, $p = .01$). The 160°H X 60°V instantaneous FOV size had the smallest deviation for altitude, and the 180°H X 88°V instantaneous FOV size had the smallest deviation for yaw rate. Roll rate and pitch variables displayed significant FOV size effects for the roll 2 and bomb release points ($F(4,17) = 4.03$, $p = .005$; $F(4,17) = 3.83$, $p = .007$), respectively. Table 1 displays the means for these effects by FOV size.

Table 1. **Significant FOV Size Effects for Deviations from Ideal Parameters by Mission Segment**

Field-of-View Sizes	126°H x 36°V	160°H x 60°V	160°H x 88°V	180°H x 88°V	300°H x 150°V
Variables					
Roll 1					
Airspeed	3.01	-1.55	0.15[a]	-0.62	-1.55
Altitude	-110.13	43.22	20.40	28.91	15.08[a]
Roll Rate	10.59	-6.38	-1.56	-2.50	0.64[a]
Apex					
Altitude	70.42	-13.89[a]	-32.08	15.83	-44.42
Yaw Rate	1.50	-0.48	-0.27	-0.25[a]	-0.52
Roll 2					
Roll Rate	5.22	4.04	-3.61	-2.37[a]	-3.64
Bomb Release Point					
Pitch	-0.63	0.04	0.00[a]	-0.10	0.71

[a]Indicates best performance.

IV. CONCLUSIONS

The present investigation compared various instantaneous field-of-view sizes against stationary field-of-view sizes of the same dimensions. It was anticipated that performance differences would be found between display type (stationary and head-driven) and FOV size. Effects of field-of-view size were found more frequently than effects for display type or for the FOV size by display type interaction. The effects found for FOV size have more statistical significance than practical significance. However, the significant differences associated with the RMS of head movement in the smallest FOV condition indicate that head movement is related to both FOV size and display type. The authors believe that this finding suggests that pilots place greater reliance on instruments in conditions where appropriate out-of-the-cockpit visual information is not available. This was most evident in the smallest stationary FOV size condition (127°H X 36°V), where there was significantly less head movement. It is difficult to draw conclusions regarding the other conditions because the observed changes were not statistically significant. The importance of the differences in head movementbehavior is unknown at this time. Overall, the results show that experienced pilots can quickly adapt to the various configurations and perform equally well whether or not the FOV is moving or stationary, except in the smallest stationary FOV condition.

The pilots that served as subjects in this experiment were highly experienced in performing the selected task. Presumably, they performed the task in the full-FOV condition in much the same manner as they would in the aircraft. The use of head position data allows us to directly assess head movement in all FOV conditions. These data show that head movement remained relatively constant for all conditions except the smallest FOV size. This size (127°H X 36°V) produced significant differences with respect to stationary or moving FOV, with larger errors for flightpath deviations. Therefore, this FOV size is judged unacceptable for performing pop-up weapons delivery. The present results also suggest that the pop-up weapons delivery task can be performed by experienced pilots, using FOV sizes as small as 160°H X 60°V, without serious detriments to flightpath adherence or bomb scores. A further conclusion is that head-tracked FOV systems can be used in the performance of air-to-ground maneuvers.

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